HIDRODINAMIK DAN PENGANGKUTAN SEDIMEN DI MUARA LAGUN SALUT-MENGKABONG, KOTA KINABALU, SABAH

BOBITA GOLAM AHAD

TESIS INI DIKEMUKAKAN UNTUK MEMENUHI SYARAT MEMPEROLEHI IJAZAH SARJANA

INSTITUT PENYELIDIKAN MARIN BORNEO
UNIVERSITI MALAYSIA SABAH
2007

UNIVERSITI MALAYSIA SABAH

BORANG PENGESAHAN STATUS TESIS @

JUDUL : **HYDRODYNAMICS AND SEDIMENT TRANSPORT AT THE TIDAL INLET OF SALUT-MENGKABONG LAGOON, KOTA KINABALU, SABAH.**

IJAZAH : **Sarjana Sains (Sains Marin)**

SESI PENGAJIAN : **2005-2007**

Saya, BOBITA GOLAM AHAD, mengaku membenarkan tesis Sarjana Sains ini disimpan di Perpustakaan Universiti Malaysia Sabah dengan syarat-syarat kegunaan seperti berikut:

1. Tesis adalah hakmilik Universiti Malaysia Sabah,
2. Perpustakaan Universiti Malaysia Sabah dibenarkan membuat salinan untuk tujuan pengajian sahaja,
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi,
4. TIDAK TERHAD.

Disahkan oleh:

(Penulis: **BOBITA GOLAM AHAD**) (TANDATANGAN PUSTAKAWAN)

Alamat tetap:
Lot 22, Teck Guan Villa,
Jln Penampang, 88300,
Kota Kinabalu, Sabah

(Penyelia: **DR. MD AZHARUL HOQUE**)

Tarikh: 23hb Mac 2007

Tarikh: 23/03/2007

CATATAN: @ Tesis dimaksudkan sebagai tesis ijazah Doktor Falsafah dan Sarjana secara penyelidikan atau disertasi bagi pengajian secara kerja kursus dan penyelidikan, atau Laporan Projek Sarjana Muda (LPSM).

DECLARATION

The materials in this thesis are original except for quotations, summaries and references, which have been duly acknowledged.

BOBITA GOLAM AHAD
PS 2005-004-002
DECEMBER 2006

ACKNOWLEDGEMENT

Praises and gratefulness to Allah S.W.T, the Almighty, for giving me the opportunity and strength to complete this study.

I would like to express heartfelt gratitude and profound thankfulness to my main supervisor Dr. Md. Azharul Hoque for his enduring patience, sincere help, invaluable advices, and encouragements during this study over the last two years. I would also like to thank my co-supervisors Dr. Shahbudin Saad and Pn. Ejria saleh for their invaluable directions and many insightful suggestions throughout my research.

I express sincere appreciation to Professor Dr. Saleem Mustafa, Director of Borneo Marine Research Institute, for his guidance and advice. My sincere gratitude also to Dr. Sitti Raehanah Muhd. Salleh, Post-graduate coordinator, for her support and cooperation. My sincere regards and thankfulness to all other faculty members of the Borneo Marine Research Institute for their friendly advice, warm hospitality, and enduring patience.

This research was supported by the International Foundation for Science, Stockholm, Sweden through a grant (W/3784-1) to Dr. Md. Azharul Hoque. I would like to thank to Fisheries Department in Terayung, Nexus Resort, Karambunai and Dalit beach Resort, for giving me the permission for field works at the study area.

My special gratitude to my beloved friend Ms. Madihah Jaffar Sidek who had been always there for me in everything I am in need. I would like to thank all the staff of Borneo Marine Research Institute especially; Mr. Asri Suari (lab assistant), Mr. Junaidi, Mr. Ismail, Mr. Roslan, Mr. Bujang, Mr. Jabdar, Mr. Ajahar, Mr. Harun, Mr. Ashraffuddin, Mr. Amizam, Mr. Montinius, Ms. Rosliah and Mr. Kennedy, for their sincere help and cooperation.

I wish to express my deep love and gratitude to my beloved and caring parents for giving me all the moral efforts and financial support. Not to forget, thanks to my brother Md. Fauzie B. Golam Ahad, and all my friends, namely, Ms. Sofea Johari, Mr. Syuhaimie, Mr. Tamrin, Madam Asmizah, Madam Norasmah, and Ms. Audrey. Finally, I wish to thanks all others who helped me to get through the past two years.

ABSTRACT

This study covered the hydrodynamics and sedimentary processes at the tidal inlet of Salut-Mengkabong Lagoon, located in the west coast of Sabah, Malaysia. Field measurements were conducted under different tidal conditions and monsoons aimed at determining water current profiles, water flux, suspended sediment concentrations and sediment flux across the main inlet as well as the entrance of Salut and Mengkabong Lagoon. Morphodynamics of the main inlet are illustrated through interpretations of profile measurements and field observation on adjacent coastline. Field measurements for water current and suspended sediment concentration were conducted in September 2005 (southwest monsoon) and February 2006 (northeast monsoon) covering both the spring and neap tidal cycles. Water surface elevations were measured using Tidalite at each transect for the complete tidal cycles during which field data were taken. Velocity measurements were conducted using Aquadopp profiler at three horizontal sampling points of each transects for complete tidal cycles at two hours interval. Water samples for measuring the suspended sediment concentration were collected at all sampling locations corresponding to velocity measurements. Beach profile were measured, using TOPCON Series AT-G6, at six transects on the adjacent coastline during southwest, northeast and inter-monsoon. The measured water currents revealed that the inlet of Salut-Mengkabong Lagoon is ebb dominated. The time-averaged velocities during the spring tidal measurements were found to be higher in the main inlet, followed by the Mengkabong and Salut entrance. Neap tidal currents were found to be steady compared to spring tidal currents. Suspended sediment concentrations were found to be higher in February 2006 (northeast monsoon) compared to that in September 2005 (southwest monsoon). Sediment flux during spring tidal cycles were found substantially higher compared to neap tidal cycles. Spring tidal measurements revealed that, ebb tidal fluxes were higher than flood tidal fluxes, leading to large ebb shoals. The February 2006 (northeast) neap tidal measurement showed higher sediment flux during flood tide. Beach profile measurements at Karambunai revealed net erosion in areas away from inlet. The net change of the profile close to the inlet was found too small, indicating that deposited materials were mostly washed out by littoral drift toward the inlet or by cross-shore transport. The profile at the throat of the inlet showed net erosion. Substantial dune erosion was observed at Karambunai beach especially in areas near the inlet. Dalit beach was found to be depositional due sediment bypassing from the updrift Karambunai beach. Due to longshore drift and ebb dominated tidal current, there were substantial depositions at the ocean side of the main inlet. Two ebb shoals were found at locations offshoreward from the inlet mouth, which developed due to the discharge of sediment by strong ebb currents, and transport of sediment by longshore current flows around the ebb shoals.

ABSTRAK

Hidrodinamik dan Pengangkutan Sedimen di Muara Lagun Salut-Mengkabong, Kota Kinabalu, Sabah.

Kajian ini meliputi proses hidrodinamik dan pengangkutan sedimen di muara Lagun Salut-Mengkabong yang terletak di pantai barat Sabah, Malaysia. Kerja lapangan telah dijalankan semasa air pasang dan surut pada kedua-dua monsun, untuk menentukan profil arus air, aliran air, kepekatan sedimen terampai dan aliran sedimen di bukaan utama muara Lagun Salut-Mengkabong dan kedua-dua Lagun Salut dan Mengkabong. Morfodinamik telah diilustrasi dengan pengukuran profil pantai dan pemerhatian di sepanjang pesisir pantai yang berhampiran dengan kedua-dua bukaan Lagun Salut dan Mengkabong. Pengukuran arus air dan kepekatan sedimen terampai dijalankan pada bulan September 2005 (monsun barat daya) dan Februari 2006 (monsun timur laut), merangkumi kedua-dua kitaran air pasang surut purnama dan air pasang surut anak. Ketinggian aras air juga diukur menggunakan Tidalite bagi setiap transek pada satu kitaran pasang surut yang lengkap. Semasa pengambilan data tersebut, halaju arus disukat bagi setiap dua jam dengan menggunakan Aquadopp profiler pada tiga titik melintang yang berbeza di kawasan kajian. Sampel air diambil untuk mengetahui kepekatan sedimen terampai bagi setiap titik tersebut. Profil pantai telah diukur menggunakan TOPCON Series AT-G6 pada enam transek di sepanjang pesisir pantai berhampiran muara utama semasa monsun barat daya, monsun timur laut dan monsun peralihan. Pengukuran arus air menunujukkan bahawa, kawasan bukaan muara Lagun Salut-Mengkabong adalah didominasikan oleh air surut. Purata masa per halaju arus air semasa air pasang adalah tinggi di kawasan muara utama diikuti dengan bukaan Lagun Mengkabong dan Salut. Arus semasa pasang surut anak adalah konstan berbanding dengan arus semasa pasang surut purnama. Kepekatan sedimen terampai adalah tinggi pada bulan Februari 2006 berbanding pada bulan September 2005. Aliran sedimen semasa kitaran air pasang surut purnama adalah lebih tinggi berbanding semasa air pasang surut anak. Aliran air adalah tinggi ketika air surut berbanding ketika aliran air pasang. Profil pantai Karambunai menunjukkan berlakunya penghakisan jauh daripada bukaan muara utama.Manakala, pemendapan sedimen berlaku berdekatan dengan bukaan muara utama dan pantai Dalit. Sedikit pemendapan sedimen berlaku berhampiran dengan muara utama akibat daripada arus bujuran pantai yang menuju ke muara utama dan aliran surut yang dominant. Profil pantai di muara utama menunjukkan berlakunya penghakisan. Jauh di mulut muara utama, terdapat dua beting pasir yang terbentuk disebabkan oleh sedimen yang keluar akibat daripada aliran arus kuat semasa air surut dan pengangkutan sedimen oleh aliran arus pantai di kawasan beting tersebut.

SYMBOLS

gm	*gram*
gm/m^2s	*gram per meter square per second*
gm/m^3	*gram per meter cube*
hr	*hour*
L	*litre*
m	*meter*
m/s	*meter per second (Speed)*
m^2	*meter square*
m^3	*cubic meter*
m^3/s	*cubic meter per second*
mL	*milliliter*
S	*second*

TABLE OF CONTENTS

		Page
DECLARATION		ii
ACKNOWLEDGEMENT		iii
ABSTRACT		iv
ABSTRAK		v
SYMBOLS		vi
TABLE OF CONTENTS		vii
LIST OF FIGURES		x
LIST OF TABLES		xiii
CHAPTER 1:	**INTRODUCTION**	**1**
1.1	INTRODUCTION	1
1.2	OBJECTIVES	3
1.3	SIGNIFICANCE OF THE STUDY	4
CHAPTER 2:	**LITERATURE REVIEW**	**5**
2.1	COASTAL LAGOON	5
2.2	TIDAL INLET	6
2.3	INLET HYDRODYNAMICS	8
2.4	INLET SEDIMENT TRANSPORT	10
2.5	INLET MORPHODYNAMICS	13
CHAPTER 3:	**STUDY AREA**	15
3.1	PHYSICAL SETTING	15
3.2	LAND USE AND LANDFORMS OF SALUT-MENGKABONG	17
3.3	GEOLOGY AND SOIL CHARACTERISTICS	18
3.4	METEO – MARINE CONDITIONS	19
3.4.1	CLIMATE	19
3.4.2	WIND SPEEDS	20
3.4.3	WAVES	21
CHAPTER 4:	**METHODOLOGY**	23
4.1	VELOCITY MEASUREMENT AND WATER SAMPLING	23
4.1.1	EQUIPMENT	23

4.1.2 SAMPLING SITE 23
4.1.3 SAMPLING TIME 25
4.1.4 WATER LEVEL MEASUREMENT 27
4.1.5 VELOCITY MEASUREMENT 27
4.1.6 WATER SAMPLING 28
4.2 BEACH PROFILE MEASUREMENT 29
4.2.1 EQUIPMENT 29
4.2.2 MEASUREMENT SCHEDULE AND LOCATIONS 29
4.2.3 MEASUREMENT PROCEDURE 30
4.3 LABORATORY ANALYSIS 32
4.3.1 WATER SAMPLE ANALYSIS FOR SUSPENDED SEDIMENT CONCENTRATION 32
4.4 DATA ANALYSIS 33
4.4.1 HYDRODYNAMICS 33
4.4.2 SEDIMENT TRANSPORT 34
4.4.3 BEACH PROFILE 34

CHAPTER 5: RESULTS 35
5.1 VELOCITY AND WATER FLUX 35
5.1.1 MAIN INLET (TRANSECT – 1) 35
5.1.1.1 SPRING TIDE 35
5.1.1.2 NEAP TIDE 38
5.1.2 SALUT ENTRANCE (TRANSECT – 2) 41
5.1.2.1 SPRING TIDE 41
5.1.2.2 NEAP TIDE 42
5.1.3 MENGKABONG ENTRANCE (TRANSECT – 3) 44
5.1.3.1 SPRING TIDE 44
5.1.3.2 NEAP TIDE 46
5.2 SUSPENDED SEDIMENT TRANSPORT 48
5.2.1 MAIN INLET (TRANSECT – 1) 48
5.2.1.1 SPRING TIDE 48
5.2.1.2 NEAP TIDE 51
5.2.2 SALUT ENTRANCE (TRANSECT – 2) 54
5.2.2.1 SPRING TIDE 54
5.2.2.2 NEAP TIDE 55
5.2.3 MENGKABONG ENTRANCE (TRANSECT – 3) 57
5.2.3.1 SPRING TIDE 57

5.2.3.2 NEAP TIDE 59

5.3 BEACH PROFILES 62

CHAPTER 6: DISCUSSION 66

6.1 VELOCITY AND WATER FLUX 66

6.1.1 SPRING TIDE 66

6.1.2 NEAP TIDE 68

6.2 SUSPENDED SEDIMENT TRANSPORT 69

6.2.1 SPRING TIDE 69

6.2.2 NEAP TIDE 70

6.3 MORPHODYNAMICS 72

6.3.1 BEACH PROFILES 72

6.3.2 DUNE RETREAT AND SHORELINE RECESSION 74

6.3.3 INLET MORPHODYNAMICS 76

CHAPTER 7: CONCLUSIONS AND RECOMENDATIONS 79

7.1 CONCLUSIONS 79

7.2 RECOMMENDATIONS FOR FURTHER RESEARCH 81

REFERENCES 82

LIST OF FIGURES

		Page
FIGURE 2.1	Typical Inlet Flow Patterns and Morphological Features (Hayes, 1975)	7
FIGURE 3.1	Topographic Map (1:50000) of the Study Area (Map Source: Gassnes *et al.*, 2004 and C-Map World for Today version 3.14)	15
FIGURE 3.2	Coastline (During High Tide) Adjacent to the Inlet	16
FIGURE 3.3	Bathymetry of the Coastal Ocean Facing the Study Area (Map Source: C-Map World for Today (Version 3.14))	17
FIGURE 3.4	Karambunai Lagoon During Low Tide	19
FIGURE 3.5	Directional Distribution of Maximum Wind Speeds in Kota Kinabalu	20
FIGURE 3.6	Wind Generated Waves Corresponding to Northwester Wind Condition for 20-Years return period	21
FIGURE 3.7	Wave Transformation and Breaking Along the Karambunai Coast	22
FIGURE 4.1	Transect for Velocity Measurement and Water Sampling (Map Source: Google Earth)	24
FIGURE 4.2	Typical Cross-Section and Sampling Locations at a Transect	25
FIGURE 4.3	Tidal Elevation During in September 2005 and February 2006	26
FIGURE 4.4	Setting Aquadop Profile Vertically Attached to the Boat	28
FIGURE 4.5	Water Sampling Using Standard Vertical Water Sampler	28
FIGURE 4.6	Locations of Transect of Beach Profile Measurement	30
FIGURE 4.7	Beach Profile Measurement	31
FIGURE 5.1	Temporal Variations of Tidal Elevation and Water Velocity at the Main Inlet (Transect-1) During One Spring Tidal Cycle in (a) September 2005, (b) February 2006 and Water Flux Across the Main Inlet in (c) September 2005 and (d) February 2006	36
FIGURE 5.2	Temporal Variations of Tidal Elevation and Water Velocity at the Main Inlet (Transect-1) During One Neap Tidal Cycle in (a) September 2005, (b) February 2006 and Water Flux Across the Main Inlet in (c) September 2005 and (d) February 2006	39
FIGURE 5.3	Temporal Variations of Tidal Elevation and Water Velocity at the Salut Entrance (Transect-2) During One Spring Tidal Cycle in (a) September 2005, (b) February 2006 and Water Flux Across the Main Inlet in (c) September 2005 and (d) February 2006	42

FIGURE 5.4	Temporal Variations of Tidal Elevation and Water Velocity at the Salut Entrance (Transect-2) During One Neap Tidal Cycle in (a) September 2005, (b) February 2006 and Water Flux Across the Main Inlet in (c) September 2005 and (d) February 2006	44
FIGURE 5.5	Temporal Variations of Tidal Elevation and Water Velocity at the Mengkabong Entrance (Transect-3) During One Spring Tidal Cycle in (a) September 2005, (b) February 2006 and Water Flux Across the Main Inlet in (c) September 2005 and (d) February 2006	46
FIGURE 5.6	Temporal Variations of Tidal Elevation and Water Velocity at the Mengkabong Entrance (Transect-3) During One Neap Tidal Cycle in (a) September 2005, (b) February 2006 and Water Flux Across the Main Inlet in (c) September 2005 and (d) February 2006	47
FIGURE 5.7	Temporal Variations of Suspended Sediment Concentration at the Main Inlet (Transect-1) During One Spring Tidal cycle in (a) September 2005, (b) February 2006 and Suspended Sediment Flux Across the Main Inlet in (c) September 2005 and (d) February 2006	49
FIGURE 5.8	Temporal Variations of Suspended Sediment Concentration at the Main Inlet (Transect-1) During One Neap Tidal cycle in (a) September 2005, (b) February 2006 and Suspended Sediment Flux Across the Main Inlet in (c) September 2005 and (d) February 2006	52
FIGURE 5.9	Temporal Variations of Suspended Sediment Concentration at the Salut Entrance (Transect-2) During One Spring Tidal cycle in (a) September 2005, (b) February 2006 and Suspended Sediment Flux Across the Salut Entrance in (c) September 2005 and (d) February 2006	55
FIGURE 5.10	Temporal Variations of Suspended Sediment Concentration at the Salut Entrance (Transect-2) During One Neap Tidal cycle in (a) September 2005, (b) February 2006 and Suspended Sediment Flux Across the Salut Entrance in (c) September 2005 and (d) February 2006	57
FIGURE 5.11	Temporal Variations of Suspended Sediment Concentration at the Mengkabong Entrance (Transect-3) During One Spring Tidal cycle in (a) September 2005, (b) February 2006 and Suspended Sediment Flux Across the Mengkabong Entrance in (c) September 2005 and (d) February 2006	59
FIGURE 5.12	Temporal Variations of Suspended Sediment Concentration at the Mengkabong Entrance (Transect-3) During One Neap Tidal cycle in (a) September 2005, (b) February 2006 and Suspended Sediment Flux Across the Mengkabong Entrance in (c) September 2005 and (d) February 2006	61
FIGURE 5.13	Beach Profile Elevations at Karambunai Beach (*K1-K3*)	63
FIGURE 5.14	Beach Profile Elevations at the Throat of the Inlet (*K4*)	64
FIGURE 5.15	Beach Profile Elevations at Dalit Beach (*D1 – D2*)	65

FIGURE 6.1	Measured and Equilibrium (Calculated) Profile at Two Transects at Karambunai Beach	74
FIGURE 6.2	Dune Retreat at the Karambunai Beach	75
FIGURE 6.3	Dune Erosion and Shoreline Retreat	76
FIGURE 6.4	Inlet of the Lagoon Looking from the Seaside During 0 m CD Tidal Level	77
FIGURE 6.5	Conceptual Illustration of Inlet Morphology	78

LIST OF TABLES

		PAGE
TABLE 4.1	Schedule for Velocity Measurement and Water Sampling	27
TABLE 4.2	Location of Transects for Beach Profile Measurement	30
TABLE 5.1	Velocity and Water Flux in Spring Tidal Cycle	37
TABLE 5.2	Velocity and Water Flux in Neap Tidal Cycle	40
TABLE 5.3	Suspended Sediment Concentrations and Sediment Flux in Spring Tidal Cycle	50
TABLE 5.4	Suspended Sediment Concentrations and Sediment Flux in Neap Tidal Cycle	53

CHAPTER 1

INTRODUCTION

1.1 Introduction

Located in the inter-tidal area of the west coast of Sabah, Malaysia, Salut-Mengkabong Lagoon plays an important role in the coastal ecology as well as the socio-economic development of the entire area (IKLIM, 2006). Of great importance are aquaculture activities, mangrove forests and tourism industries. The lagoon system is characterised by mangroves, some seagrasses, shallow coastal waters, tidal flushings and little flow of water from inland areas (IKLIM, 2006). Mangrove forests play a significant role as natural sediment traps and provide protection for fish larvae, juveniles, and compositional support for mollusks and crustaceans (Gassner *et al.*, 2004).

Immediately after the tidal inlet, the lagoon splits into two parts: Salut and Mengkabong. The existence of two resorts in these two parts, Nexus Karambunai and Shangri-La's Rasa Ria, makes this area as one of the eco-tourism destinations in Sabah. In addition, another development project Nexus Resort Residence-Karambunai along the coast of Salut division is on-going (IKLIM, 2006). This increase in the development pressure adjacent to the lagoon gives rise to a number of issues: the erosion, accretion, and morphodynamics behaviour along the coastline, water quality and nearshore marine habitats.

Increasing pressure from aquaculture and eco-tourism activities in this area has led to the depletion of mangrove forests and seagrass beds, with a consequence of affecting the overall coastal environment. Development activities outside the lagoon due to different construction and reclamation projects tend to increase soil erosion, which is transported into the adjacent nearshore waters and the tributaries of the lagoon (IKLIM, 2006). The drainage of rainwater carries sediment from dynamic development areas through the inlet by small streams or adjacent coast (IKLIM, 2006). On the other side, longshore transport along the adjacent coastline deposits substantial sediments to the inlet area, which enters to the lagoon with flood tide, and some are deposited at the ocean side in front of the tidal inlet. Due to excess sediment accretion, the area is becoming shallower and the tidal inlet is becoming narrower thereby affecting the coastal ecology of the area (Saleh *et al.*, 2005). Increasing suspended sediment accumulation affects the valuable marine inhabitants on the seabed and the water column (Saleh *et al.*, 2005).

Although the Salut-Mengkabong Lagoon is an important component of the west coast of Sabah's ecosystem as well as, socio-economically, the physical coastal processes of the lagoon and inlet are yet to be documented. Understanding the hydrodynamics and sedimentary processes of a tidal inlet are emphasised over other studies of a lagoon ecosystem. Tidal inlet of a lagoon is the most dynamic area for water circulation and suspended sediment transports (Bruun, 1969). The water exchange and sediment flux through the inlet govern the spatio-temporal distribution of hydro-geomorphologic characteristics and physico-chemical water properties, which are important for the description of productivity and carrying capacity of a lagoon. The flow of water current creates natural flushing to maintain good water circulation and for physical water properties, such as the salinity, pH, temperatures, and dissolved oxygen. Furthermore, the flow of water current also transports suspended sediments to the specific area, which is important to sea life, as plenty of fishes migrate to this area to breed. Knowledge in hydrodynamics and suspended sediment transport are important to help determine the profile of an area. The major natural components that control the factors of the tidal inlet evolution are mean sea levels, tides, wave climates and sediments supply (Hayes, 1980). So, it is important to investigate the hydrodynamics and sedimentary processes at the inlets of Salut-Mengkabong Lagoon.

An important aspect of typical flood and ebb currents is that currents usually flow toward the inlet near the shoreline. CERC (2003) reported that, along the up drift shoreline, obliquely incident waves transport sediment alongshore and directed toward the inlet. Across the inlet mouth, the waves breaking upon the ebb shoal transport sediment both into the inlet and toward the down drift shoreline. Flood flow decelerates and diverges beyond to the lagoon side of the inlet mouth, which causes sediment deposition at the flood shoals. On the other side, the ebb flow carries sediment from the flood shoals and inlet channel, which ultimately deposit as the ebb shoals beyond the ocean mouth of the inlet. Due to the complex interactions between wave energy, tidal current, wave-current interactions, tidal prism, sediment source, and suspended sediment dynamics, tidal inlet may migrate or remain fixed in its location. The littoral system is the principal sediment source that influences the stability of the inlets (Oertel, 1988). A study on shoreline and inlet changes on Salut-Mengkabong lagoon, (Saleh *et al.*, 2005) reported sediment deposition near the inlet and down drift locations. For understanding the morphodynamic behaviour of the study area, it is necessary to study the sediment transport across the inlet and beach profiles along the adjacent coast.

1.2 Objectives

To improve understanding of the complex interactions between currents, tidal flows, sedimentation, and related phenomena that determine the hydrodynamics and sediment transport behaviour of the tidal inlet and adjacent coastline of the Salut-Mengkabong lagoon, the objectives of this research are:

1. To study water current and water flux at different tidal conditions during two monsoons.
2. To study the suspended sediment concentration and sediment flux at different tidal conditions during two monsoons.
3. To study the morphodynamics of the inlet and adjacent coastline.

1.3 Significance of the Study

This study provides baseline information on water currents, water exchange, suspended sediment concentration, and sediment flux at the inlet and the morphodynamics of the inlet and adjacent coastline. The findings of this study will be useful for more detailed studies on inlet stability, and the impacts of sedimentation on the lagoon system.

Furthermore, findings of this research provides information suitable for developing sustainable aquaculture projects, controlling environmental pollution, and planning integrated coastal zone management programs in the area.

CHAPTER 2

LITERATURE REVIEW

2.1 Coastal Lagoon

Coastal lagoons are shallow aquatic ecosystem developed at the interface between coastal terrestrial and marine ecosystem. The water mass of a lagoon is impounded by sedimentary barriers (barrier islands) and connected to the open sea by one or several openings (inlets) in the barrier. The tidal inlets are maintained due to action of tidal currents against the effects of longshore current. Lagoons have a global implication to continental shelf and oceanic processes because of the exchanges of water, contaminants, and sediment between the lagoons and the coastal seas. They are the route by which the sediment is transported by surface runoff or river flows from the interior of the land masses. During transport through the lagoon, the sedimentary processes change through continual deposition, re-erosion, and transport, and certain fractions of input sediment become permanently trapped, while others are transported into the sea. Consequently, the lagoon processes act as a filter on the sediment input. Moreover, chemical alterations can occur within the lagoon that can cause the mineralogical characteristics of some of the constituent particles to alter. The loss of estuary wetlands or lagoon (including shallow inter- and sub-tidal areas) will lead to serious hydraulic modification of tidal and river channels (Carter, 1988), and to a marked effect on biological productivity as such areas often act as nurseries for fishes at the adjacent coastal waters.

Lagoons are sensitive areas that play an important role among the coastal zone ecosystem as they provide suitable breeding areas for many species. Fisheries and aquaculture, tourism, urban, industrial and agricultural developments are typical uses that are not only uncontrolled but also competing (Gonenc & Wolflin, 2005). As a result, the existing quality and future ability to sustain the productivity of lagoon ecosystems is being compromised. Understanding the unique system of lagoon processes is the primary step to maintain the long-term health of both the ecological and economic system of a lagoon and surrounding areas.

2.2 Tidal Inlet

A tidal inlet generally refers to a short, narrow waterway that connects a lagoon or bay with a larger parent body of water (i.e., ocean or lake), and experiences the inflow and outflow of water due to tidal flow (CERC, 2003). Tidal inlets are found at many places along the world's coasts. The long-term evolution of these inlets commands a growing socio-economic and scientific interest. Man first started impacting these tidal inlet systems more than a thousand years ago through reclaiming inter-tidal areas, dredging channels, and closing basins (Stive, 2003).

Inlets are of environmental importance in exchanging water from restricted back barrier areas and in keeping the dynamic equilibrium of the coastal system. They play an important role in navigation, representing the only access to some harbours or coastal populations. A great number of inlets have direct and indirect impact on regional economy (i.e. navigation, aquaculture, tourism, conservation). Several works based on inlet evolution monitoring are helpful in the planning of coastal management (Kana & Mason, 1988; Cialone *et al.*, 1999; Forbes & Solomon, 1999; Galgano & Leatherman, 1999).

Inlet circulation is governed by tidal range, bay geometry, inlet geometry, presence and configuration of structures, bottom topography, and non-tidal forces such as wind and river inflow. The rise and fall of the ocean tide is the primary force at the inlet area. Representative circulation patterns and morphological features at inlets are shown in Figure 2.1. Flood currents form channels on both sides of the inlet entrance. As water passes through the inlet and enters the bay, the current is aligned with the inlet and flows over the flood shoal where the velocity is reduced and material is deposited. This process forms a flood ramp, which is the sloped front face of the flood shoal. During ebb tide, the primary conduits of water are channels located between the flood shoal and the barrier island. These ebb channels merge at the inlet forming a main ebb channel. Strong ebb currents exiting the inlet form a jet (Joshi 1982; Joshi & Taylor, 1983; Mehta & Joshi, 1988). As the jet exits the inlet, it expands and loses velocity, depositing material onto the ebb shoal.

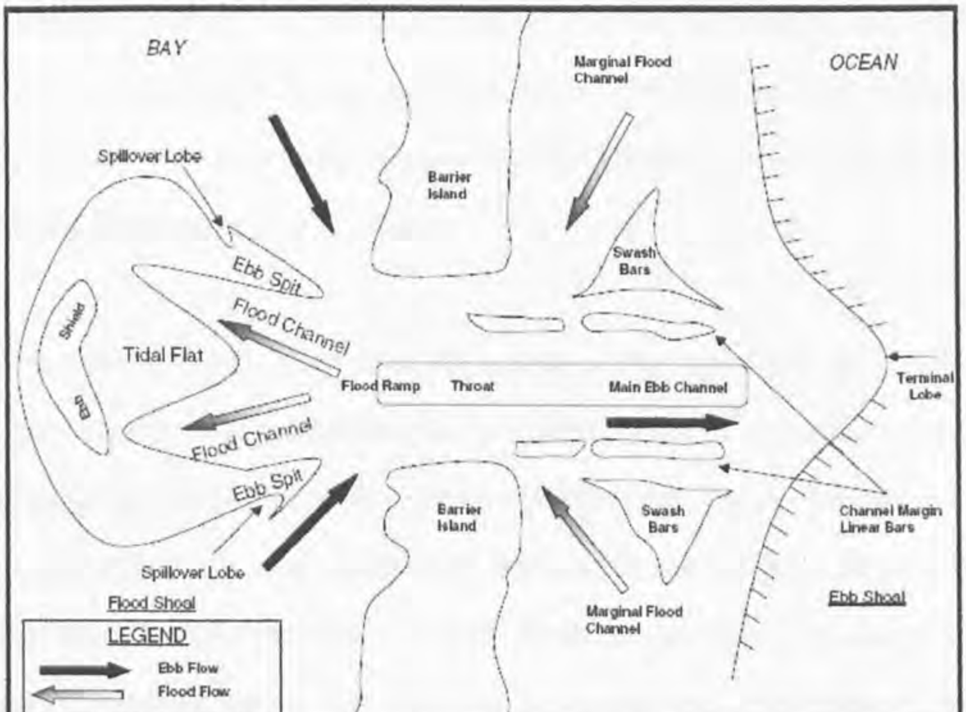

Figure 2.1: Typical inlet flow patterns and morphological features (Hayes, 1975).

The pattern of flood and ebb circulation is common, but every inlet has a unique pattern due to the local situation. For example, the main ebb channel may be in the centre of the inlet or along one side. Factors that control the local circulation include inlet geometry, tide range, bay-channel orientation, distribution of discharge through channels, wave climate, number and configuration of jetties, and dredging activity (Militello & Hugher, 2000)

2.3 Inlet Hydrodynamics

Understanding the inlet hydrodynamics is the key for understanding the sedimentary processes, morphodynamic changes and other ecological effects of the lagoon system. Water masses entering and leaving the lagoon determine the interaction of ecosystem parameters in the lagoon and adjacent coastal waters. The exchange of water, including various dissolved substances or suspended material, between the open ocean and coastal areas has a pronounced impact on the entire oceanic system. This exchange is quite vigorous in some areas characterised by complex bathymetry, and sometimes controls the evolution of the bathymetry itself. Even more important is that the temporal variability of the water exchange between the tidal basins and the open ocean is not sufficiently understood (Emil *et al.*, 2003).

The hydrodynamics at an inlet are mainly caused by simply an ebb-flood tidal system, tide, wind stress, freshwater influx and wind waves (4 – 25 m/s periods), which significantly forces the effects on the system (CERC, 2003). During flood tides, currents are funneled toward the inlet mouth from the sea. In the absence of jetty, or other controlling structure, the flood flow is typically most dominant along the ocean shoreline of the adjacent barrier island. The flood flow converges and accelerates in the throat. Upon its discharge, the flood flow diverges and decelerates beyond the inlet bayside mouth. The reverse ebb flows, which are rarely symmetrical, discharges to the inlet ocean mouth like a free jet and deposits sediment load in an ebb shoal. Flood and ebb dominance is due to the asymmetry of the tidal currents, which means that the average peak of flood or ebb currents is stronger than its opposing current. Tidal asymmetry is common in the inlet area, where it is identified as flood dominant if flood is stronger than ebb currents, and ebb dominant if ebb is stronger than flood currents. In an inlet and bay system in which no tributary input or other significant non-tidal forcing is present, the net discharge is zero through the inlet, even through there is asymmetry in the tidal current.

If the oceanic forces are purely sinusoidal, and there are no non-linear effects such as over tide generation, but only an attenuation of the tidal constituents as the tide propagates into the estuary, the response of the estuarine surface elevations must also be sinusoidal. Purely sinusoidal oceanic forcing and estuarine response can only result in symmetric tidal velocities even in the case of phase lags between the oceanic forcing and estuarine tidal response. Asymmetric tidal velocities are of major importance to the evolution of inlet hydrodynamics. Flood dominant systems supply sediment in the lagoon while ebb-dominant systems flush sediment seaward (Boon & Byrne, 1981; Aubrey & Speer, 1985). Thus, when the duration of the falling tide exceeds that of the rising tide, leading to stronger flood currents, the system is defined as `Flood-dominant', and 'Ebb dominant' when the duration of the falling tide is smaller than that of the rising tide, leading to stronger ebb currents (Speer & Aubrey, 1985; Speer *et al.*, 1991). Tidal velocity asymmetry in inlets is generally attributed to the generation of compound tidal constituents and higher harmonics (also known as over tides) of the principal astronomical tidal constituents (Aubrey & Speer, 1985; Friedrichs *et al.*, 1992).

There are many approaches that were used to evaluate inlet hydrodynamics: analytical expressions, numerical models, physical models, and field measurements. Earlier developments of inlet hydrodynamics achieved reasonable results using simplified approaches of steady flow hydraulics to understand inlet currents and response of the bay or lagoon tide (Brown, 1928). Keulengan (1951, 1967) solved the one dimensional depth-averaged shallow water wave equations for flow analytically. Others have formulated a variety of analytical solutions for inlet hydrodynamics (van deKreeke, 1967; Oliveira, 1970; Shemdin & Forney, 1970; King, 1974; Mehta & Ozsoy, 1978; Escofier & Walton, 1979; DiLorenzo, 1988). Paralleling analytical development, physical models were used in different studies. More recently, numerical models have provided greater refinements and details using one-, two- and three-dimensional long wave equations of motions (Harris & Bodine, 1977; Butler, 1980; Amein & Kraus, 1991). However, analytical and numerical solutions are based on simple assumptions and need boundary and initial conditions. For this, premodeling analysis of hydrological and morphometric parameters of the lagoon should be conducted through field investigation. Such studies for Salut-Mengkabong Lagoon have never yet been carried out and hence a baseline study on the inlet hydrodynamics through field investigation is essentially the first step for further development on understanding this area.

2.4 Inlet Sediment Transport

Understanding the sediment dynamics is of great importance for the inlet stability and lagoon ecosystem. Knowledge of suspended sediment dynamics is also important to determine the possibility and transport of suspended sediment adherent contaminants. Lindsay *et al.* (1996) mentioned that the variability of suspended sediment concentration (SSC) is fundamental in sedimentology, geomorphology, engineering, biology, ecology, and biogeochemistry. Suspended sediment concentration in coastal waters is influenced

REFERENCES

Amein, A. and Kraus, N. C. 1991. *DYNLET1: Dynamic implicit numerical model of one-dimensional tidal flow thought inlets.* Technical Report No: 91-10. U.S. Army Engineer Waterways Experiment Station, Vicksburg.

Aubrey, D. G. and Speer, P. E. 1985. A study of non-linear tidal propagation in shallow inlet/estuarine systems, Part I: Observations. *Estuarine, Coastal and Shelf Science.* **21**: 185-205.

Bagnold, R. A. 1963. The movement of desert sand. *Proceedings of the Royal Society of London.* Series A. **157**: 94-620.

Balloch, D., Davies, C. E. and Jones, F. H. 1976. Biological assessment of water quality in three British rivers: the North Esk (Scotland), the Ivel (England) and the Taf (Wales). *Water Pollution Control.* **75**: 92.

Boon, J. D. and Bryne, R. J. 1981. On basin hypsometry and the morphodynamic response of coastal inlet systems. *Marine Geology.* **40**: 27-48.

Brown, E. I. 1928. Inlets on sandy coasts. *Proceedings of the American Society of Civil Engineers.* **54**(I): 503-523.

Bruun, P. and Gerritsen, F. 1960. *Stability of Coastal Inlets.* Amsterdam: North Holland Publishing Co.

Bruun, P. 1969. Tidal inlets on alluvial shores. In: Castanares, A. A. and Phleger, F.B. (eds.). *Lagunas Costeras, UN Simposio UNAM-UNESCO.* **1**: 349-366.

Butler, H. L. 1980. *Estuarine and Wetland Processes: With Emphasis on Modeling; Marine Science, Volume 11.* New York: Plenum press.

Carter, R. W. G. 1988. *Coastal Environments: An Introduction to the Physical, Ecological, and Cultural Systems of Coastlines.* London: Academic Press.

CERC. 2003. *Coastal Engineering Manual.* Coastal Engineering Research Centre, U.S. Army Engineer Waterways Experiment Station, Vicksburg.

Cialone, M. A., Seabergh, W. C. and Watson, K. D. 1999. Flood shoal response to inlet modifications at Barnegat Inlet, New Jersey. *Proceedings of the Coastal Sediments.* American Society of Civil Engineers. **99**:1434–1449.

Davis, R. A. and Ethington, R. L. 1976. *Beach and nearshore sedimentation.* Society of Economic Paleontologists and Mineralogists (SEPM) Special Publication.

Davis, R. A. 1985. *Coastal Sedimentary Environments.* (2nd edition). New York: Springer-Verlag.

De Vriend, H. J., Bakkel, W. T. and Bilse, D. P. 1994. A morphological behaviour model for the outer delta of mixed-energy tidal inlets. *Coastal Engineer.* **23**: 305-327.

DHI. 2005. *Sabah Shoreline Management Plan.* Environmental Protection Department, Kota Kinabalu, Sabah.

DiLorenzo, J. L. 1988. The overtide and filtering response of small inlet/bay systems. Aubrey, D. G. and Weishar, L. (eds.). *Hydrodynamics and Sediment Dynamics of Tidal Inlets.* New York: Springer-Verlag.

Emil, V. S., Gotz, F. and Jorg-Olaf, W. 2003. First and higher-order dynamical controls on water exchanges between tidal basins and the open ocean. A case study for the East Frisian Wadden Sea. *Ocean Dynamics.* **53**: 146–165.

Escoffier, F. F. 1940. The stability of tidal inlets. *Shore and Beach.* **8**(4): 114-115.

Escoffier, F. F., and Walton, T. L. 1979. Inlet stability solutions for tributary inflow. *Journal of the Waterway, Port, Coastal and Ocean Division, American Society of Civil Engineers.* **105**: 341-355.

FitzGerald, D. M., Hubbard, D. K., and Nummedal, D. 1978. Shoreline changes associated with tidal inlets along the South Carolina coasts. *Proceedings of the Coastal zone.* American Society of Civil Engineers. **1**: 1973-1994.

FitzGerald, D. M, and Nummedal, D. 1983. Response characteristics of an ebb-dominated tidal inlet channel. *Journal of Sedimentary Petrology.* **53**(3): 833-845.

FitzGerald, D. M. 1984. Interactions between the ebb-tidal delta and the landward shoreline: Price Inlet, SC. *Journal of Sedimentary Petrology.* **54**: 1303-1318.

FitzGerald, D. M. 1988. Shoreline erosional-depositional processes associated with tidal inlets, hydrodynamics and sediment dynamics. *Coastal and Estuarine Studies.* **29**: 186 – 225.

FitzGerald, D. M., and Montello, T. M. 1993. Back barrier and inlet sediment response to the breaching of spit and formation of new inlet, Cape Cod, Massachusets. In: Aubrey, D. G. and Giese, G. S. (eds.). Formation and evolution of multiple tidal inlets. *Coastal and Estuarine Studies.* **44**: 158-185.

Forbes, D. L., and Solomon, S. M. 1999. Inlet division and coastal instability following tidal prism diversion. *Proceedings of Coastal Sediments.* American Society of Civil Engineers. **1**: 1418–1433.

Friedrichs, C. T., Lynch, D. R. and Aubrey, D. G. 1992. Velocity asymmetries in frictionally-dominated tidal estuary/lagoons: Longitudinal and Lateral Variability. In: Prandle, D. (ed.). *Dynamics and Exchanges in Estuaries and the Coastal Zone.* Washington DC: American Geophysical Union.

Galgano, F. A. and Leatherman, S. P. 1999. Beach erosion, tidal inlets and politics: the Fire Island story. *Shore and Beach.* **67**(2): 26–32.

Gassner, A., Zarinah, W. and Shahbudin, S. (ed.). 2004. *Community participation in river management conservation of Salut-Mengkabong*. Interim Report January-December 2004: WGI Research and Monitoring. UMS, Sabah, Malaysia.

Gelfenbaum, G. 1983. Suspended-sediment response to semidiurnal and fortnightly tidal variations in a mesotidal estuary: Columbia River, USA. *Marine Geology*. **52**: 39–57.

Gonenc, E. and Wolfin, J. P. 2005. *Coastal Lagoons: Ecosystem Processes and Modeling for Sustainable Use and Development*. London: CRC.

Harris, D. L. and Bodine, B. R. 1977. *Comparison of numerical and physical hydraulic models, Masonboro Inlet, North Carolina*. Report No: 6. U.S. Army Engineer Waterways Experiment Station, Vicksburg.

Hayes, M. O. 1973. *Coastal Geomorphology, Coates: The Investigation of Brim and Processes in the Coastal Zone*. New York: Academic Press.

Hayes, M. O. 1975. Morphology of Sand Accumulations in Estuaries. In: Cronin, L. E. (ed.). *Estuarine Research, Volume 2*. New York: Academic Press.

Hayes, M. O. 1980. General morphology and sediment patterns in tidal inlets. *Sedimentary Geology*. **26**: 139-156.

http:// www. Google Earth.com.

Hubbard, D. K., Oertel, G. and Nummedal, D. 1979. The role of waves and tidal currents in the development of tidal-inlet sedimentary structures and sand body geometry: examples from North Carolina, South Carolina, and Georgia. *Journal of Sedimentary Petrology*. **49** (4):1073-1092.

Iklim. 2006. *Coastal Environmental Studies For Nexus Resort Residence at Karambunai, Menggatal*. Kota Kinabalu: Environmental Impact Assessments, Environmental Protection Department, Sabah, Malaysia.

Joshi, P. B. 1982. Hydromechanics of tidal jets. *Journal of the Waterway, Port, Coastal and Ocean Division*. **108:** 239-253.

Joshi, P. B. and Taylor, R. B. 1983. Circulation induced by tidal jets. *Journal of the Waterway, Port,Coastal and Ocean Division*. **109**: 445-464.

Kamphuis, W. 2002. *Introduction to Coastal Engineering and Management*. Singapore: World scientific publishing.

Kana, T. W. and Mason, J. E. 1988. Evolution of an ebb tidal-delta after an inlet relocation. *Coastal and Estuarine Studies*. **29**: 382–409.

Keulegan, G. H. 1951. *Third progress report on tidal flow in entrances, water level fluctuations of basins in communication with seas*. Report No: 1146. National Bureau of Standards, Washington DC.

Keulegan, G. H. 1967. *Tidal flow in entrances water-level fluctuations of basins in communications with seas.* Technical Bulletin No: 14. Committee on Tidal Hydraulics, U.S. Army Engineer Waterways Experiment Station, Vicksburg.

King, D.B. 1974. *The dynamics of inlets and bays.* Technical Report No: 2. Coastal and Oceanographic Engineering Laboratory, University of Florida, Gainesville.

Kitheka, J. U., Ongwenyi, G. S. and Mavuti, K. M. 2003. Fluxes and exchange of suspended sediment in tidal inlets draining a degraded mangrove forest in Kenya Estuarine. *Coastal and Shelf Science.* **56**: 655–667.

Lindsay, P., Balls, P. W. and West, J. R. 1996. Influence of tidal range and river discharge on suspended particulate matter fluxes in the Forth estuary (Scotland). *Estuarine, Coastal and Shelf Science.* **42**(1): 63-82.

Mehta, A. J., Bryne, R. J. and De Alteris, J. T. 1976. Measurements of bed friction in tidal inlets. *Proceedings of the 5th Coastal Engineering Conference.* American Society of Civil Engineers **1**:1701-1720.

Mehta, A. J. and Ozsoy, E. 1978. *Inlet Hydraulics, Stability of the Tidal Inlets: Theory and Engineering.* Amsterdam: Elsevier Scientific Publishing.

Mehta, A. J. and Joshi, P. B. 1988. Tidal inlet hydraulics. *Journal of Hydraulic Engineering.* **114**(11): 1321-1338.

Militello, A. and Hughes, S. A. 2000. Circulation patterns at tidal inlets with jetties hughes. *US Army Cops of Engineers CETN.* **4**: 29

National Hydrographic Centre, Royal Malaysian Navy. 2005. *Tide Tables Malaysia 2005. Volume 2.*

National Hydrographic Centre, Royal Malaysian Navy. 2006. *Tide Tables Malaysia 2006. Volume 2.*

Nummedal, D. and Humphries, S. M. 1978. *Hydraulics and dynamics of north Inlet, South Carolina, 1975-76.* Report No: 16. General Investigation of Tidal Inlets, US Army Engineer Waterways Experiment Station, Vicksburg.

O'Brien, M.P. 1931. Estuary tidal prism related to entrance areas. *Civil Engineer.* **1**: 738.

Oertel, G. F. 1988. Processes of sediment exchange between tidal inlets, ebb deltas and barrier islands. In: Aubrey, D.G., and Weishar, L. (eds.). *Hydrodynamics and Sediment Dynamics of Tidal Inlets.* New York: Springer-Verlag.

Oliveira, I. B. M. 1970. Natural flushing ability in tidal inlets. *Proceedings of the 12th Coastal Engineering Conference.* American Society of Civil Engineers. **3**(111): 1827-1845.

Ridderinkhof H., van der Ham, R. and van der Lee, W. 2000. Temporal variations in concentration and transport of suspended sediments in a channel–flat system in the Ems-Dollard estuary. *Continental Shelf Research.* **20**(12-13): 1479-1493.

Saleh, E., Hoque, M. A., Saad, S. and Magupin, S. 2005. A study on shoreline and inlet changes of Salut-Mengkabong Lagoon Sabah, Malaysia using remote sensing images. *Proceedings of the Asian Conference on Remote Sensing, Vietnam.* (In CD).

Schoellhamer, D. H. 2002. Variability of suspended-sediment concentration at tidal to annual time scales in San Francisco Bay, USA. *Continental Shelf Research.* **22**(11-13):1857-1866.

Shemdin, O. H. and Forney, R. M. 1970. Tidal motion in bays. *Proceedings of the 12th Coastal Engineering Conference.* American Society of Civil Engineers. **3**: 2225-2242.

Speer, P. E. and Aubrey, D. G. 1985. Study of non-linear tidal propagation in shallow inlet/estuarine systems: Part II: Theory. *Estuarine, Coastal and Shelf Science.* **21**: 207 – 224.

Speer, P. E., Aubrey, D. G. and Friedrichs, C. T. 1991. Nonlinear hydrodynamics of shallow tidal inlet/estuary systems. In: Parker, B. (ed.). *Tidal Hydrodynamics.* New York: Wiley.

Stauble, D. K., Da Costa, S. L., Monroe, K. L. and Bhogal, V. K. 1988. Inlet Flood Tidal Delta Development Through Sediment Transport Processes, Hydrodynamics, and Sediment Dynamics of Tidal Inlets. In: Aubrey, D. G. and Weishar, L. (ed.). *Coastal and Estuarine Studies.* New York: Springer-Verlag.

Stive, M. J. F., Roelvink, J. A. and de Vriend, H. J. 1990. Large-scale coastal evolution concept. *Proceedings of the 22nd International Conference on Coastal Engineer.* American Society of Civil Engineers. **1**: 1962-1974.

Stive, M. J. F. and Wang, Z. B. 2003. Morphodynamic Modeling of Tidal Basins and Coastal Inlets. In: Lakhan, C. (ed.). *Advances in Coastal Modeling.* Amsterdam: Elsevier.

Uncles, R. J. 2002. Estuarine physical processes research: some recent studies and progress. *Estuarine, Coastal and Shelf Science.* **55:** 829-856.

Vila-Concejo, A., Ferreira, O. B., Matias, A. and Dias, J. M. A. 2003. The first two years of an inlet: sedimentary dynamics. *Continental Shelf Research.* **23**: 1425–1445.

Wang, Z. B., Louters, I. and de Vriend, H. J. 1995. Morphodynamic modeling for a tidal inlet in the Wadden sea. *Marine Geology.* **126**: 289-300.

Yang, S. L., Shi, Z., Zhao, H. Y., Li, P., Dai, S. B. and Gao, A. 2004. Effects of human activities on the Yangtze River suspended sediment flux into the estuary in the last century. *Hydrology and Earth System Sciences.* **8** (6): 1210–1216.

Zenkovich, V. P. 1967. *Subamarine Sandbars and Related Formations, Processes of Coastal Development*. New York: Oliver and Boyd, Ltd.